US009362891B2

(12) **United States Patent**
Man

(10) **Patent No.: US 9,362,891 B2**
(45) **Date of Patent: Jun. 7, 2016**

(54) **METHODS AND APPARATUS FOR TUNING A COMMUNICATION DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 294 days.

(21) Appl. No.: **13/558,716**

(22) Filed: **Jul. 26, 2012**

(65) **Prior Publication Data**

US 2014/0030987 A1 Jan. 30, 2014

(51) **Int. Cl.**

H04B 1/40	(2015.01)
H03J 1/00	(2006.01)
H04B 1/3827	(2015.01)

(52) **U.S. Cl.**

CPC ***H03J 1/0008*** (2013.01); ***H04B 1/3838*** (2013.01); *H03J 2200/10* (2013.01)

(58) **Field of Classification Search**

CPC H04B 1/40; H04B 1/18; H04B 1/0458

USPC 455/77, 67.14, 120, 160, 82, 87, 123, 455/133; 333/17.3; 343/850

See application file for complete search history.

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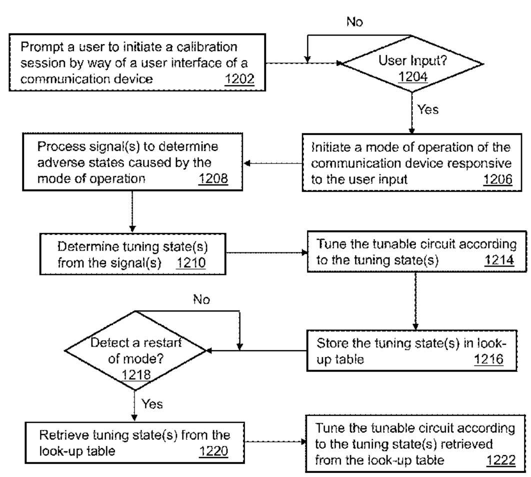
(57) **ABSTRACT**

A system that incorporates teachings of the subject disclosure may include, for example, method for initiating a mode of operation of a communication device, measuring a signal to determine an adverse operational effect on the communication device, determining a tuning state from the signal to compensate for the adverse operational effect, tuning a circuit of the communication device having a variable reactance according to the tuning state, storing the tuning state in a memory of the communication device, and tuning the circuit according to the tuning state retrieved from the memory responsive to detecting a reoccurrence of the mode of operation of the communication device. Other embodiments are disclosed.

24 Claims, 7 Drawing Sheets



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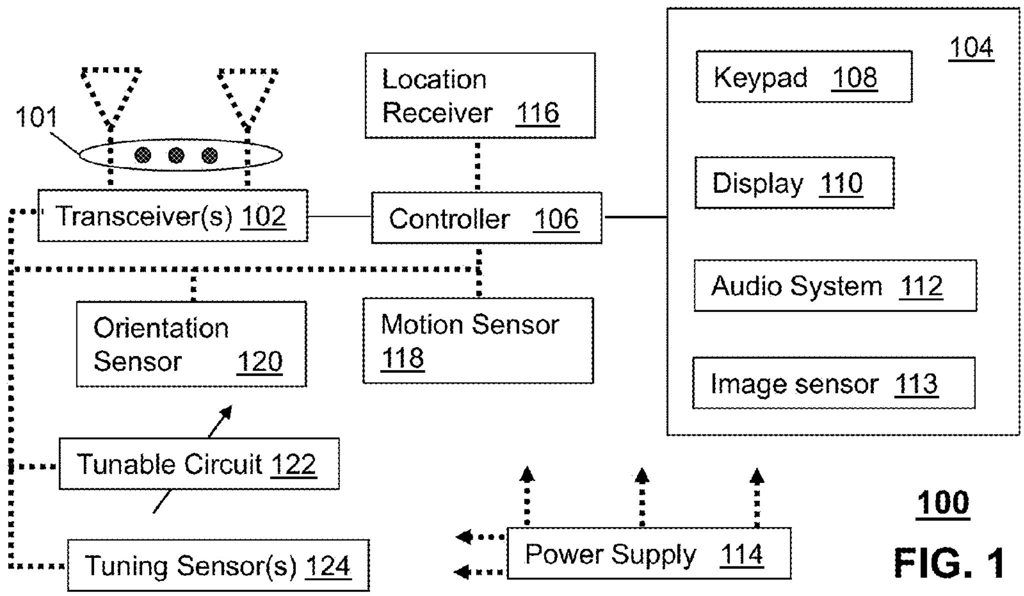

101
Transceiver(s) 102
Location Receiver 116
Controller 106
104
Keypad 108
Display 110
Audio System 112
Image sensor 113
Orientation Sensor 120
Motion Sensor 118
Tunable Circuit 122
Tuning Sensor(s) 124
Power Supply 114
100

FIG. 1

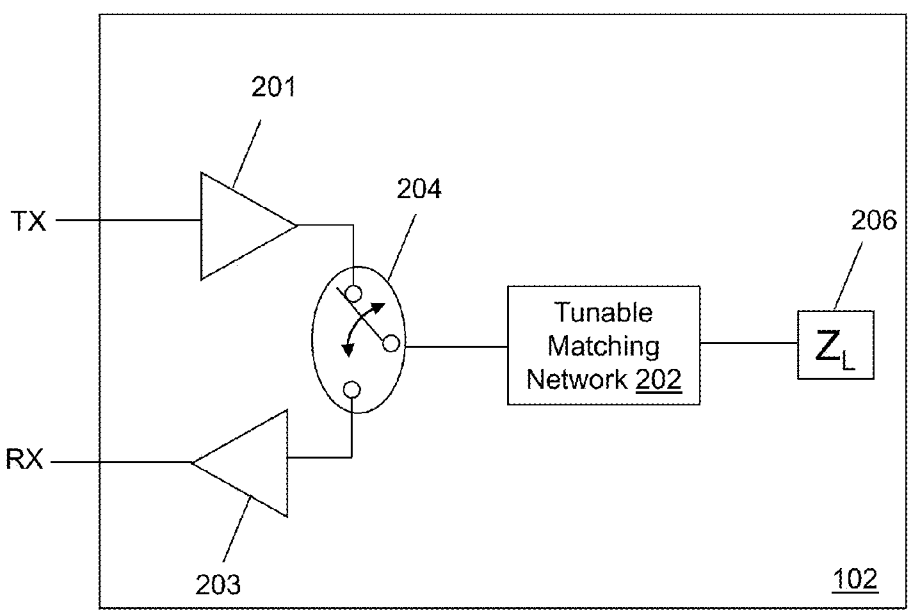
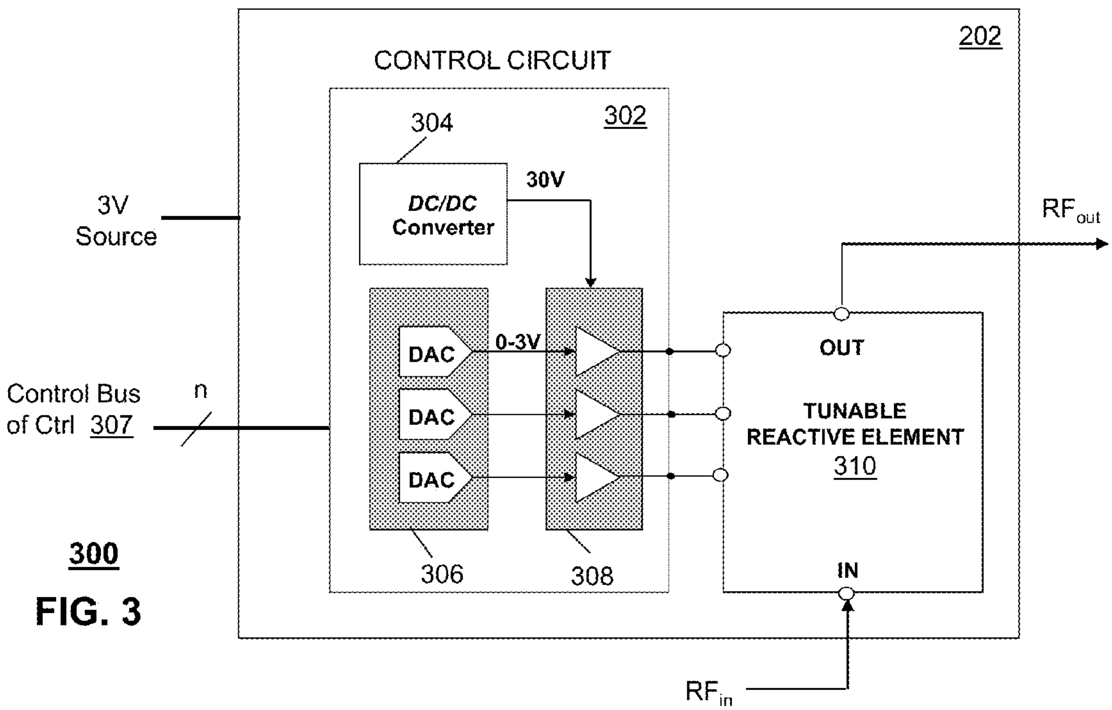
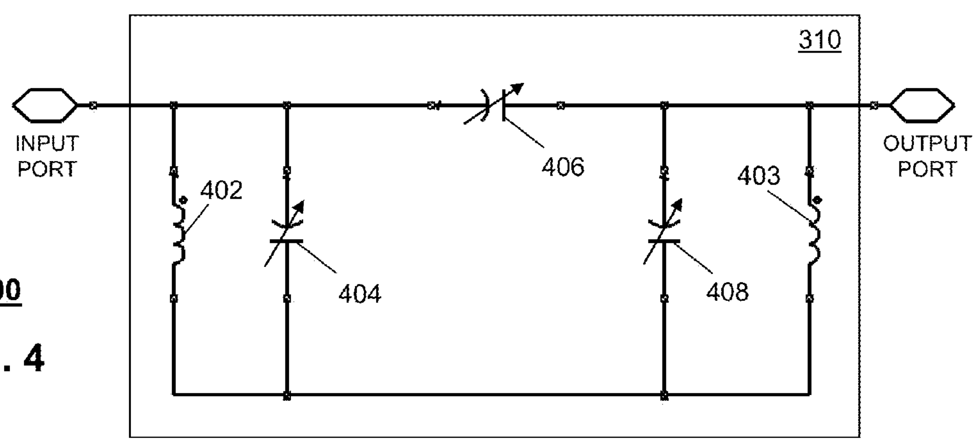

201
204
206
TX
RX
Tunable Matching Network 202
Z_L
203
102

FIG. 2



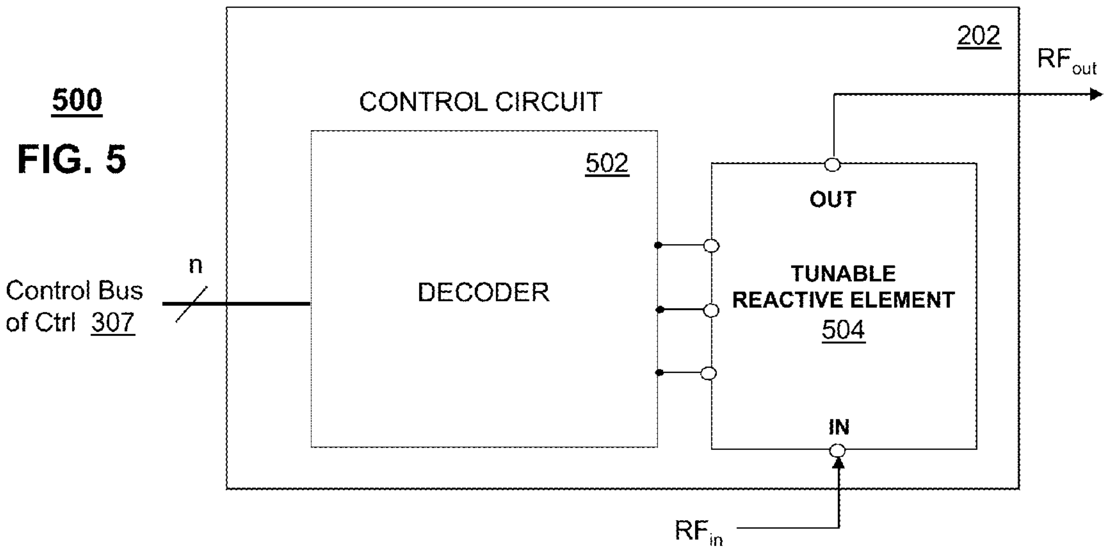
300

FIG. 3



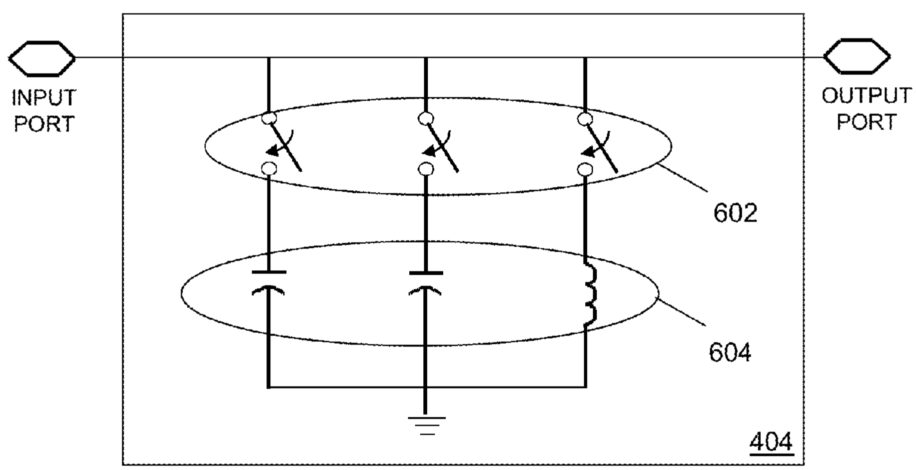
400

FIG. 4



500

FIG. 5



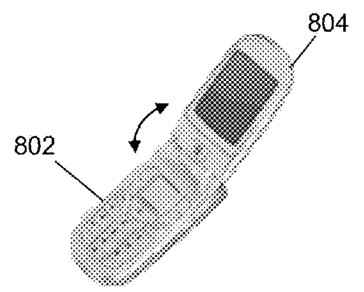
600

FIG. 6

LOOK-UP TABLE

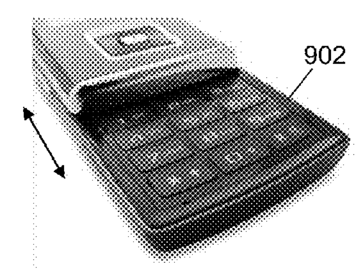
Band 1; Use Case 1; Desired tuning state
Band 1; Use Case 2; Desired tuning state
⋮
Band 1; Use Case n; Desired tuning state
Band 2; Use Case 1; Desired tuning state
Band 2; Use Case 2; Desired tuning state
⋮
Band 2; Use Case n; Desired tuning state
Band N; Use Case 1; Desired tuning state
Band N; Use Case 2; Desired tuning state
⋮
Band N; Use Case n; Desired tuning state

FIG. 7



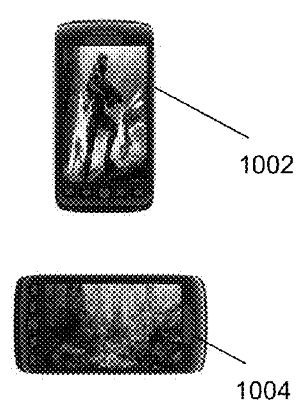
800

FIG. 8



900

FIG. 9



1000

FIG. 10

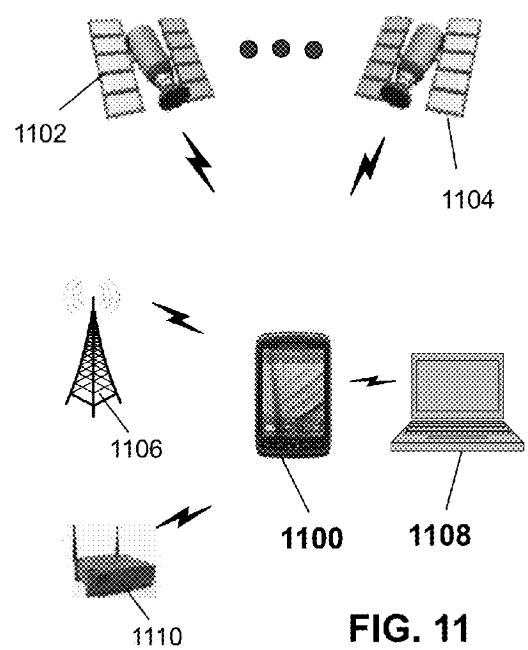


FIG. 11

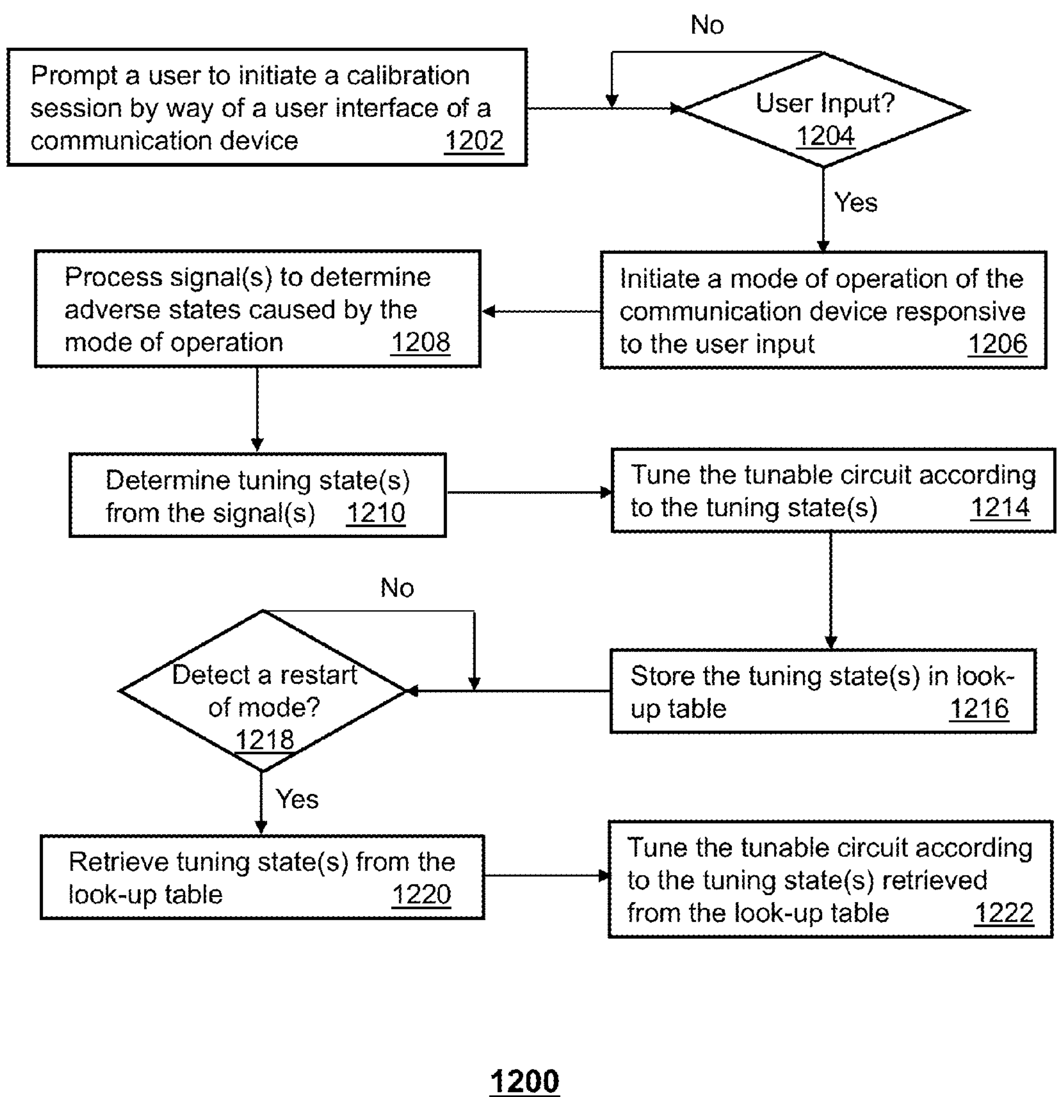
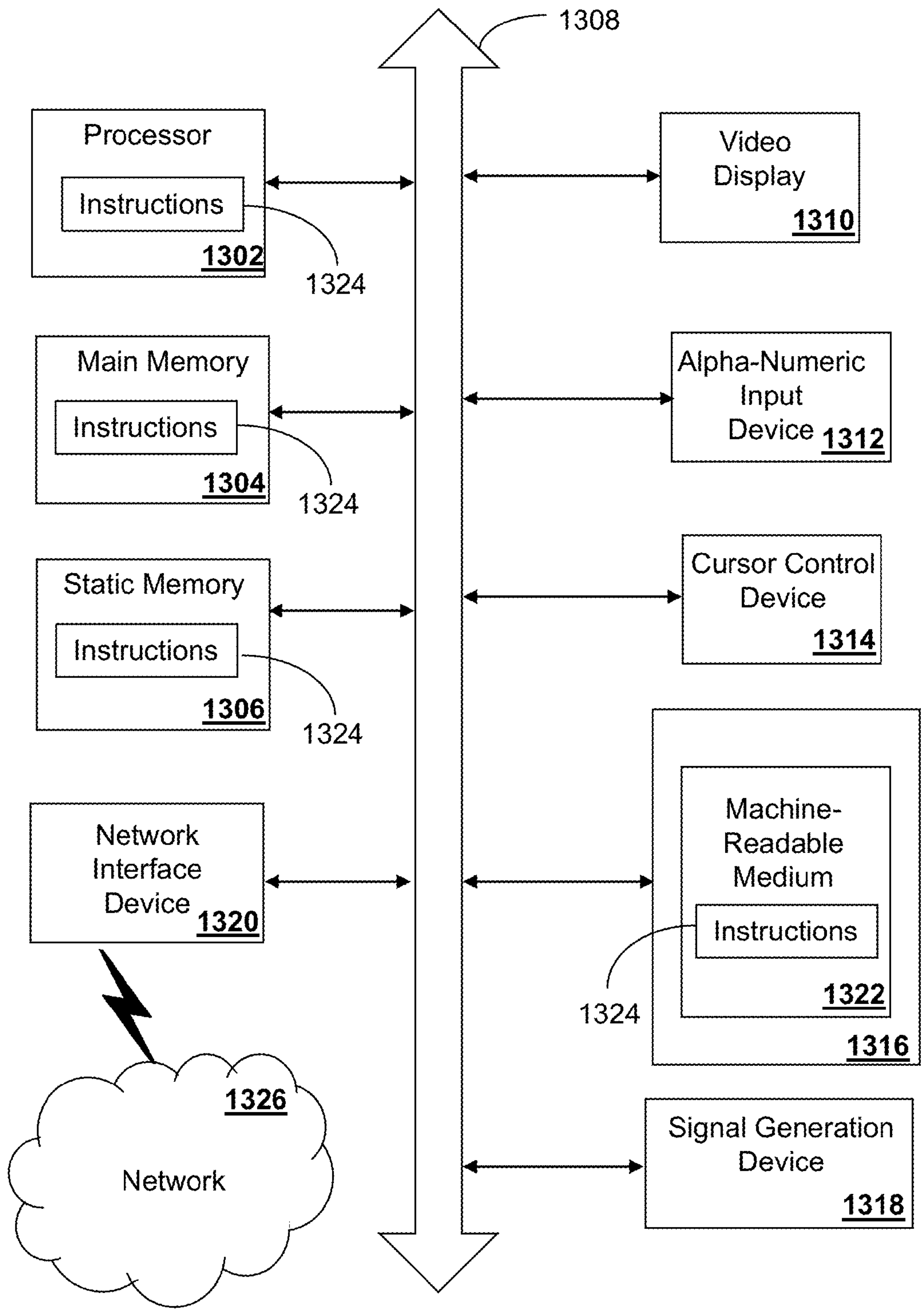

Prompt a user to initiate a calibration session by way of a user interface of a communication device 1202
User Input? 1204
No
Yes
Initiate a mode of operation of the communication device responsive to the user input 1206
Process signal(s) to determine adverse states caused by the mode of operation 1208
Determine tuning state(s) from the signal(s) 1210
Tune the tunable circuit according to the tuning state(s) 1214
Store the tuning state(s) in look-up table 1216
Detect a restart of mode? 1218
No
Yes
Retrieve tuning state(s) from the look-up table 1220
Tune the tunable circuit according to the tuning state(s) retrieved from the look-up table 1222
1200

FIG. 12


1308
Processor
Instructions
1302
1324
Main Memory
Instructions
1304
1324
Static Memory
Instructions
1306
1324
Network Interface Device
1320
1326
Network
Video Display
1310
Alpha-Numeric Input Device
1312
Cursor Control Device
1314
Machine-Readable Medium
Instructions
1322
1324
1316
Signal Generation Device
1318

1300

FIG. 13

METHODS AND APPARATUS FOR TUNING A COMMUNICATION DEVICE

FIELD OF THE DISCLOSURE

The subject disclosure relates to methods and apparatus for tuning a communication device.

BACKGROUND

Cellular communication devices such as cellular telephones, tablets, and laptops can support multi-cellular access technologies, peer-to-peer access technologies, personal area network access technologies, and location receiver access technologies, which can operate concurrently. Cellular communication devices have also integrated a variety of consumer features such as MP3 players, color displays, gaming applications, cameras, and other features. Cellular communication devices can be required to communicate at a variety of frequencies, and in some instances are subjected to a variety of physical and functional use conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** depicts an illustrative embodiment of a communication device;

FIG. **2** depicts an illustrative embodiment of a portion of a transceiver of the communication device of FIG. **1**;

FIGS. **3-6** depict illustrative embodiments of a tunable matching network of the transceiver of FIG. **2**;

FIG. **7** depicts an illustrative embodiment of a look-up table utilized by the communication device of FIG. **1** for controlling tunable reactive elements utilized by the communication device;

FIGS. **8-11** depict illustrative physical and operational use cases of a communication device;

FIG. **12** depicts an exemplary method that can be used for tuning components of the communication device of FIG. **1**;

FIG. **13** depicts an illustrative diagrammatic representation of a machine in the form of a computer system within which a set of instructions, when executed, may cause the machine to perform any one or more of the methodologies disclosed herein.

DETAILED DESCRIPTION

The subject disclosure describes, among other things, illustrative embodiments for tuning a communication device. Other embodiments are described by the subject disclosure.

One embodiment of the subject disclosure includes a communication device having an antenna, a tunable circuit having a variable reactive impedance, a memory storing computer instructions, a processor coupled to the memory, the tunable circuit, and the antenna. The processor, responsive to executing the computer instructions, can perform operations including initiating a mode of operation of the communication device, measuring a signal to determine an adverse state caused by the mode of operation of the communication device, determining a tuning state from the signal, tuning the tunable circuit according to the tuning state to compensate for the adverse state, storing the tuning state in a look-up table, detecting a reinitiating of the mode of operation of the communication device, retrieving the tuning state from the look-up table, and tuning the tunable circuit according to the tuning state retrieved from the look-up table.

One embodiment of the subject disclosure includes a computer-readable storage medium having computer instructions, which when executed by a processor, cause the processor to perform operations, including initiating a mode of operation of a communication device, measuring a signal to determine an adverse effect on one or more performance metrics of the communication device, determining a tuning state from the signal, tuning a circuit having a variable reactance according to the tuning state, storing in a memory the tuning state, detecting a reoccurrence of the mode of operation of the communication device, retrieving the tuning state from the memory, and tuning the circuit according to the tuning state retrieved from the memory.

One embodiment of the subject disclosure includes a method for initiating, by a communication device comprising a processor, a mode of operation of the communication device, measuring, by the communication device, a signal to determine an adverse operational effect on the communication device, determining, by the communication device, a tuning state from the signal to compensate for the adverse operational effect, tuning, by the communication device, a circuit of the communication device having a variable reactance according to the tuning state, storing, by the communication device, the tuning state in a memory of the communication device, and tuning, by the communication device, the circuit according to the tuning state retrieved from the memory responsive to detecting a reoccurrence of the mode of operation of the communication device.

FIG. **1** depicts an illustrative embodiment of a communication device **100**. The communication device **100** can comprise one or more transceivers **102** coupled to one or more antennas **101**, each transceiver having transmitter and receiver sections (herein transceiver **102** or transceivers **102**), a tunable circuit **122**, one or more tuning sensors **124**, a user interface (UI) **104**, a power supply **114**, a location receiver **116**, a motion sensor **118**, an orientation sensor **120**, and a controller **106** for managing operations thereof. The transceiver **102** can support short-range or long-range wireless access technologies such as Bluetooth, ZigBee, Wireless Fidelity (WiFi), Digital Enhance Cordless Telecommunications (DECT), or cellular communication technologies, just to mention a few.

Cellular technologies can include, for example, Global System for Mobile (GSM), Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), Universal Mobile Telecommunications (UMTS), World interoperability for Microwave (WiMAX), Software Defined Radio (SDR), Long Term Evolution (LTE), as well as other next generation wireless communication technologies as they arise. The transceiver **102** can also be adapted to support circuit-switched wireline access technologies such as Public Switched Telephone Network (PSTN), packet-switched wireline access technologies such as TCP/IP, Voice over IP—VoIP, etc., or combinations thereof.

The tunable circuit **122** can comprise variable reactive elements such as variable capacitors, variable inductors, or combinations thereof that are tunable with digital and/or analog bias signals. The tunable circuit **122** can represent a tunable matching network coupled to the antenna **101** to compensate for a change in impedance of the antenna **101**, a compensation circuit to compensate for mutual coupling in a multi-antenna system, an amplifier tuning circuit to control operations of an amplifier of the transceiver **102**, a filter tuning circuit to alter a pass band of a filter used by the transceiver **102**, and so on.

The tuning sensors **124** can be placed at any stage of the transceiver **102** such as, for example, before or after a matching network **202**, and/or at a power amplifier **201** as shown in FIG. **2**. The tuning sensors **124** can utilize any suitable sensing technology such as directional couplers, voltage dividers, or other sensing technologies to measure signals at any stage of the transceiver **102**. The digital samples of the measured signals can be provided to the controller **106** by way of analog-to-digital converters included in the tuning sensors **124**. Data provided to the controller **106** by the tuning sensors **124** can be used to measure, for example, transmit power, transmitter efficiency, receiver sensitivity, power consumption of the communication device **100**, frequency band selectivity by adjusting filter passbands, linearity and efficiency of power amplifiers, specific absorption rate (SAR) requirements, and so on. The controller **106** can be configured to execute one or more tuning algorithms to determine desired tuning states of the tunable circuit **122** based on the foregoing measurements.

The UI **104** can include a depressible or touch-sensitive keypad **108** with a navigation mechanism such as a roller ball, a joystick, a mouse, or a navigation disk for manipulating operations of the communication device **100**. The keypad **108** can be an integral part of a housing assembly of the communication device **100** or an independent device operably coupled thereto by a tethered wireline interface (such as a USB cable) or a wireless interface supporting, for example, Bluetooth. The keypad **108** can represent a numeric keypad commonly used by phones, and/or a QWERTY keypad with alphanumeric keys. The UI **104** can further include a display **110** such as monochrome or color LCD (Liquid Crystal Display), OLED (Organic Light Emitting Diode) or other suitable display technology for conveying images to an end user of the communication device **100**. In an embodiment where the display **110** is touch-sensitive, a portion or all of the keypad **108** can be presented by way of the display **110** with navigation features.

The display **110** can use touch screen technology to also serve as a user interface for detecting user input. As a touch screen display, the communication device **100** can be adapted to present a user interface with graphical user interface (GUI) elements that can be selected by a user with a touch of a finger. The touch screen display **110** can be equipped with capacitive, resistive or other forms of sensing technology to detect how much surface area of a user's finger has been placed on a portion of the touch screen display. This sensing information can be used to control the manipulation of the GUI elements or other functions of the user interface. The display **110** can be an integral part of the housing assembly of the communication device **100** or an independent device communicatively coupled thereto by a tethered wireline interface (such as a cable) or a wireless interface.

The UI **104** can also include an audio system **112** that utilizes audio technology for conveying low volume audio (such as audio heard in proximity of a human ear) and high volume audio (such as speakerphone for hands free operation). The audio system **112** can further include a microphone for receiving audible signals of an end user. The audio system **112** can also be used for voice recognition applications. The UI **104** can further include an image sensor **113** such as a charged coupled device (CCD) camera for capturing still or moving images.

The power supply **114** can utilize common power management technologies such as replaceable and rechargeable batteries, supply regulation technologies, and/or charging system technologies for supplying energy to the components of the communication device **100** to facilitate long-range or short-range portable applications. Alternatively, or in combination, the charging system can utilize external power sources such as DC power supplied over a physical interface such as a USB port or other suitable tethering technologies.

The location receiver **116** can utilize location technology such as a global positioning system (GPS) receiver capable of assisted GPS for identifying a location of the communication device **100** based on signals generated by a constellation of GPS satellites, which can be used for facilitating location services such as navigation. The motion sensor **118** can utilize motion sensing technology such as an accelerometer, a gyroscope, or other suitable motion sensing technology to detect motion of the communication device **100** in three-dimensional space. The orientation sensor **120** can utilize orientation sensing technology such as a magnetometer to detect the orientation of the communication device **100** (north, south, west, and east, as well as combined orientations in degrees, minutes, or other suitable orientation metrics).

The communication device **100** can use the transceiver **102** to also determine a proximity to or distance to cellular, WiFi, Bluetooth, or other wireless access points by sensing techniques such as utilizing a received signal strength indicator (RSSI) and/or signal time of arrival (TOA) or time of flight (TOF) measurements.

The controller **106** can utilize computing technologies such as a microprocessor, a digital signal processor (DSP), and/or a video processor with associated storage memory such as Flash, ROM, RAM, SRAM, DRAM or other storage technologies for executing computer instructions, controlling, and processing data supplied by the aforementioned components of the communication device **100**.

Other components not shown in FIG. **1** can be added to the communication device **100**. For example, the communication device **100** can include a slot for inserting or removing an identity module such as a Subscriber Identity Module (SIM) card. SIM cards can be used for identifying and registering subscriber services, executing computer programs, storing subscriber data, and so forth.

The communication device **100** as described herein can operate with more or less of the circuit components shown in FIG. **1**. It is further noted that communication device **100** be an integral part of consumer or industrial devices such as cellular phones, computers, laptops, tablets, utility meters, telemetry measurement devices, and so on.

FIG. **2** depicts an illustrative embodiment of a portion of the wireless transceiver **102** of the communication device **100** of FIG. **1**. In GSM applications, the transmit and receive portions of the transceiver **102** can include amplifiers **201**, **203** coupled to a tunable matching network **202** that is in turn coupled to an impedance load **206**. The impedance load **206** in the present illustration can be an antenna as shown in FIG. **1** (herein antenna **206**). A transmit signal in the form of a radio frequency (RF) signal (TX) can be directed to the amplifier **201** which amplifies the signal and directs the amplified signal to the antenna **206** by way of the tunable matching network **202** when switch **204** is enabled for a transmission session. The receive portion of the transceiver **102** can utilize a pre-amplifier **203** which amplifies signals received from the antenna **206** by way of the tunable matching network **202** when switch **204** is enabled for a receive session. Other configurations of FIG. **2** are possible for other types of cellular access technologies such as CDMA, UMTS, LTE, and so forth. These undisclosed configurations are applicable to the subject disclosure.

FIGS. **3-4** depict illustrative embodiments of the tunable matching network **202** of the transceiver **102** of FIG. **2**. In one embodiment, the tunable matching network **202** can comprise a control circuit **302** and a tunable reactive element **310**. The control circuit **302** can comprise a DC-to-DC converter

304, one or more digital to analog converters (DACs) 306 and one or more corresponding buffers 308 to amplify the voltage generated by each DAC. The amplified signal can be fed to one or more tunable reactive components 404, 406 and 408 such as shown in FIG. 4, which depicts a possible circuit configuration for the tunable reactive element 310. In this illustration, the tunable reactive element 310 includes three tunable capacitors 404-408 and two inductors 402-403 with a fixed inductance. Circuit configurations such as "Tee", "Pi", and "L" configurations for a matching circuit are also suitable configurations that can be used in the subject disclosure.

The tunable capacitors 404-408 can each utilize technology that enables tunability of the reactance of the component. One embodiment of the tunable capacitors 404-408 can utilize voltage or current tunable dielectric materials. The tunable dielectric materials can utilize, among other things, a composition of barium strontium titanate (BST). In another embodiment, the tunable reactive element 310 can utilize semiconductor varactors, or micro-electromechanical systems (MEMS) technology capable of mechanically varying the dielectric constant of a capacitor. Other present or next generation methods or material compositions that result in a voltage or current tunable reactive element are applicable to the subject disclosure for use by the tunable reactive element 310 of FIG. 3.

The DC-to-DC converter 304 can receive a DC signal such as 3 volts from the power supply 114 of the communication device 100 in FIG. 1. The DC-to-DC converter 304 can use technology to amplify a DC signal to a higher range (e.g., 30 volts) such as shown. The controller 106 can supply digital signals to each of the DACs 306 by way of a control bus 307 of "n" or more wires or traces to individually control the capacitance of tunable capacitors 404-408, thereby varying the collective reactive impedance of the tunable matching network 202. The control bus 307 can be implemented with a two-wire serial bus technology such as a Serial Peripheral Interface (SPI) bus (referred to herein as SPI bus 307). With an SPI bus 307, the controller 106 can transmit serialized digital signals to configure each DAC in FIG. 3. The control circuit 302 of FIG. 3 can utilize digital state machine logic to implement the SPI bus 307, which can direct digital signals supplied by the controller 106 to the DACs to control the analog output of each DAC, which is then amplified by buffers 308. In one embodiment, the control circuit 302 can be a stand-alone component coupled to the tunable reactive element 310. In another embodiment, the control circuit 302 can be integrated in whole or in part with another device such as the controller 106.

Although the tunable reactive element 310 is shown in a unidirectional fashion with an RF input and RF output, the RF signal direction is illustrative and can be interchanged. Additionally, either port of the tunable reactive element 310 can be connected to a feed point of the antenna 206, a structural element of the antenna 206 in an on-antenna configuration, or between antennas for compensating mutual coupling when diversity antennas are used, or when antennas of differing wireless access technologies are physically in close proximity to each other and thereby are susceptible to mutual coupling. The tunable reactive element 310 can also be connected to other circuit components of a transmitter or a receiver section such as filters, amplifiers, and so on, to control operations thereof.

In another embodiment, the tunable matching network 202 of FIG. 2 can comprise a control circuit 502 in the form of a decoder and a tunable reactive element 504 comprising switchable reactive elements such as shown in FIG. 6. In this embodiment, the controller 106 can supply the control circuit 402 signals via the SPI bus 307, which can be decoded with Boolean or state machine logic to individually enable or disable the switching elements 602. The switching elements 602 can be implemented with semiconductor switches, MEMS, or other suitable switching technology. By independently enabling and disabling the reactive elements 607 (capacitor or inductor) of FIG. 6 with the switching elements 602, the collective reactive impedance of the tunable reactive element 504 can be varied by the controller 106.

The tunable reactive elements 310 and 504 of FIGS. 3 and 5, respectively, can be used with various circuit components of the transceiver 102 to enable the controller 106 to manage performance factors such as, for example, but not limited to, transmit power, transmitter efficiency, receiver sensitivity, power consumption of the communication device 100, frequency band selectivity by adjusting filter passbands, linearity and efficiency of power amplifiers, SAR requirements, among other operational parameters.

FIG. 7 depicts an illustration of a look-up table stored in memory, which can be indexed by the controller 106 of the communication device 100 of FIG. 1 according to physical and/or functional use cases of the communication device 100. A physical use case can represent a physical state of the communication device 100, while a functional use case can represent an operational state of the communication device 100. For example, for a flip phone 800 of FIG. 8, an open flip can represent one physical use case, while a closed flip can represent another physical use case. In a closed flip state (i.e., bottom and top flips 802-804 are aligned), a user is likely to have his/her hands surrounding the top flip 802 and the bottom flip 804 while holding the phone 800, which can result in one range of load impedances experienced by an internal or retrievable antenna (not shown) of the phone 800. The range of load impedances of the internal or retrievable antenna can be determined by empirical analysis and while the communication device is in operation by a consumer as will be described below.

With the flip open a user is likely to hold the bottom flip 802 with one hand while positioning the top flip 804 near the user's ear when an audio system of the phone 800, such audio system 112 of FIG. 1, is set to low volume, and voice channel is active. If, on the other hand, the audio system 112 is in speakerphone mode, it is likely that the user is positioning the top flip 804 away from the user's ear. In these arrangements, different ranges of load impedances can be experienced by the internal or retrievable antenna, which can be analyzed empirically. The low and high volume states of the audio system 112, as well as, a determination that a voice channel is active illustrates varying functional use cases.

For a phone 900 with a slideable keypad 904 (illustrated in FIG. 9), the keypad in an outward position can present one range of load impedances of an internal antenna, while the keypad in a hidden position can present another range of load impedances, each of which can be analyzed empirically and while a consumer is operating the communication device. For a smartphone 1000 (illustrated in FIG. 10) presenting a video game, an assumption can be made that the user is likely to hold the phone away from the user's ear in order to view the game. Placing the smartphone 1000 in a portrait position 1002 can represent one physical and operational use case, while utilizing the smartphone 1000 in a landscape position 1004 presents another physical and operational use case.

The number of hands and fingers used in the portrait mode may be determined by the particular type of game being played by the user. For example, a particular video game may require a user interface where a single finger in portrait mode may be sufficient for controlling the game. In this scenario, it may be assumed that the user is holding the smartphone **1000** in one hand in portrait mode and using a finger with the other. By empirical analysis, or by measurements when the communication device is in use by a consumer, a possible range of impedances of the internal antenna(s) of the communication device can be determined when using the video game in portrait mode. Similarly, if the video game selected has a user interface that is known to require two hands in landscape mode, another estimated range of impedances of the internal antenna can be determined.

A multimode phone **1100** capable of facilitating multiple access technologies such as GSM, CDMA, LTE, WiFi, GPS, and/or Bluetooth in two or more combinations can provide additional insight into possible ranges of impedances experienced by two or more internal antennas of the multimode phone **1100**. For example, a multimode phone **1100** that provides GPS services by processing signals received from a constellation of satellites **1102**, **1104** can be empirically analyzed when other access technologies are also in use. Suppose, for instance, that while navigation services are enabled, the multimode phone **1100** is facilitating voice communications by exchanging wireless messages with a cellular base station **1106**. In this state, an internal antenna of the GPS receiver may be affected by a use case of a user holding the multimode phone **1100** (e.g., near the user's ear or away from the user's ear). The effect on the GPS receiver antenna and the GSM antenna by the user's hand position can be determined.

Suppose in another scenario that the antenna of a GSM transceiver is in close proximity to the antenna of a WiFi transceiver. Further assume that the GSM frequency band used to facilitate voice communications is near the operational frequency of the WiFi transceiver. Also assume that a use case for voice communications may result in certain physical states of the multimode phone **1100** (e.g., slider out), which can result in a probable hand position of the user of the multimode phone **1100**. Such a physical and functional use case can affect the impedance range of the antenna of the WiFi transceiver as well as the antenna of the GSM transceiver.

A close proximity between the WiFi and GSM antennas and the near operational frequency of the antennas may also result in cross-coupling between the antennas. Mutual or cross-coupling under these circumstances can be measured empirically. Similarly, empirical measurements of the impedances of other internal antennas can be measured for particular physical and functional use configurations when utilizing Bluetooth, WiFi, Zigbee, or other access technologies in peer-to-peer communications with another communication device **1108** or with a wireless access point **1110**. In diversity designs such as multiple-input and multiple output (MIMO) antennas, physical and functional use cases of a communication device can be measured to determine how best to configure a tunable compensation circuit **122** such as shown in FIG. **1**.

The number of physical and functional use cases of a communication device **100** can be substantial when accounting for combinations of access technologies, frequency bands, antennas of different access technologies, antennas configured for diversity designs, and so on. These combinations, however, can be analyzed to determine load impedances of the antenna(s), mutual coupling between them, and the effects on transmitter and receiver performance metrics. Mitigation strategies to reduce mutual coupling, counter the effect of varying load impedances, and to improve other performance metrics of the transceiver **102** can also be determined. The measured data collected and corresponding mitigation strategies can be recorded in the look-up table of FIG. **7** and indexed according to combinations of physical and functional use cases detected by the communication device **100**. The information stored in the look-up table can be used in open-loop RF tuning applications to initialize tunable circuit components of the transceiver **102**, as well as, tuning algorithms that control operational aspects of the tunable circuit components.

FIG. **12** depicts an illustrative method **1200** that can be used in portions of the devices of FIGS. **1-6**. Method **1200** can begin with step **1202** in which the controller **106** of the communication device **100** can be adapted to prompt a user to initiate a calibration session by way of a user interface **104** of the communication device **100**. The prompt can be audible, visual, or a combination thereof. The calibration process can be automatically initiated such as a first power-on sequence of the communication device **100** after it is purchased, or calibration can be a periodic feature that is invoked at different times such as, for example, when purchasing a new software application, or when invoking new features of the communication device **100**, or combinations thereof. The prompt presented by way of the user interface **104** can request that the user invoke one or more modes of operation of the communication device **100** to test for adverse effects.

The mode of operation of the communication device **100** can include a data communication session (e.g., 3G or 4G session), a voice communication session (GSM, UMTS, or CDMA session), an execution of a software application (e.g., a video game, location services, navigation services, etc.), or combinations thereof. The mode of operation of the communication device **100** can result in combinations of physical and functional use cases as previously described by way of illustration of FIGS. **8-11**. If user input invoking the requested mode is detected in step **1204**, the communication device **100** proceeds to step **1206** where it initiates the requested mode. At step **1208**, the controller **106** can receive signals from the tuning sensors **124** and process the signals to determine adverse states caused by the initiated mode of operation of the communication device **100**.

An adverse state can include, for example, detecting a change in impedance of the antenna **101** from a reflection coefficient determined from one of the measured signals resulting in a mismatch between the tunable matching network **202** and the load impedance **206** (i.e., the antenna **101**). Another adverse state can include measuring by way of the tuning sensors **124** backscattering current from one of the antennas **101** indicating that there is mutual coupling between multiple antennas. Further adverse effects can include detecting an undesirable efficiency or linearity of an amplifier based on signals measured by the tuning sensors **124**. Adverse effects can also include an unexpected increase in power consumption, or other effects that are measurable and controllable.

Based on the adverse states detected in step **1208**, the controller **106** can determined at step **1210** from the measured signals and corresponding adverse states one or more tuning states that can be used to program the tunable circuit **122**, and thereby compensate for the adverse states. For example, the controller **106** can determine from a measured reflection coefficient a new tuning state (i.e., new impedance) of the tunable matching network **202** to more closely match the present impedance of the antenna **101**. Similarly, based on a measure of efficiency or linearity, the controller **106** can determine new tuning states of a power tuning circuit (not shown) of amplifier **201** as mentioned earlier such as, for example, setting bias voltages, supply voltage settings, and/or a new impedance state of a variable reactive circuit coupled to the amplifier **201** to singly or collectively improve the efficiency and/or linearity of the amplifier **201**. Other tuning states can be determined for other tunable devices such as tunable bandpass filters, and so on.

At step **1214**, the controller **106** proceeds to tune the tunable circuit **122** by supplying digital and/or analog signals to the tunable circuit **122** to establish the tuning states determined in step **1210**. At step **1216**, the controller **106** can store the tuning states determined at step **1210** in the look-up table of FIG. **7** according to the physical and functional use cases detected in the mode of operation of the communication device **100** initiated at step **1206**. Once recorded in the look-up table, the controller **106** can monitor at step **1218** future reoccurrences of the mode of operation that was just calibrated. If a reoccurrence of the same mode is detected, the controller **106** proceeds to step **1220** where it retrieves the tuning states from the look-up table according to this mode, and tunes the tunable circuit **122** according to the retrieved tuning states at step **1222**. In one embodiment, step **1220** can be performed without performing **1208** to measure adverse states. In another embodiment, the controller **106** can be configured to periodically, or each time there's a reoccurrence of a mode previously calibrated, reinitiate step **1208** after tuning the tunable circuit **122** with the tuning states retrieved from the look-up table to determine if recalibration is necessary. If the controller **106** determines that an adverse state is present, the controller **106** can be configured to repeat steps **1202-1216**.

Steps **1218-1222** provide a rapid approach to counteracting adverse effects on performance parameters of the communication device **100** before they happen. The calibration process described by method **1200** can be invoked for any number of modes of operation of the communication device **100**. Method **1200** can also be adapted to store tuning states according to any number of modes of operation of the communication as they occur.

Upon reviewing the aforementioned embodiments, it would be evident to an artisan with ordinary skill in the art that said embodiments can be modified, reduced, or enhanced without departing from the scope of the claims described below. For example, method **1200** can be adapted to also perform closed-loop tuning. That is, after the retrieved tuning states have been used to tune the tunable circuit **122**, the controller **106** can be adapted to continuously measure the operational parameters of the communication device **100** by way of the tuning sensors **124** to fine-tune incremental adverse affects that cannot be mitigated by static tuning states.

Method **1200** can also be adapted to detect when a user of the communication device **100** installs a new software application, and can invoke the calibration process to further augment the tuning states stored in the look-up table. Method **1200** can also be configured to monitor use patterns of a user of the communication device **100**, measure adverse effects and mitigation strategies that are predictable from such use patterns, and store additional tuning states in the look-up table to further mitigate adverse states of the communication device **100**. Method **1200** can also be adapted to model adverse states and in some instances ascertain a mathematical model for tuning states that can be applied in real-time during a mode of operation of the communication device.

Other embodiments can be applied to the subject disclosure without departing from the scope of the claims described below.

It should be understood that devices described in the exemplary embodiments can be in communication with each other via various wireless and/or wired methodologies. The methodologies can be links that are described as coupled, connected and so forth, which can include unidirectional and/or bidirectional communication over wireless paths and/or wired paths that utilize one or more of various protocols or methodologies, where the coupling and/or connection can be direct (e.g., no intervening processing device) and/or indirect (e.g., an intermediary processing device such as a router).

FIG. **13** depicts an exemplary diagrammatic representation of a machine in the form of a computer system **1300** within which a set of instructions, when executed, may cause the machine to perform any one or more of the methods discussed above. One or more instances of the machine can operate, for example, as the communication device **100** of FIG. **1**. In some embodiments, the machine may be connected (e.g., using a network) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client user machine in server-client user network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

The machine may comprise a server computer, a client user computer, a personal computer (PC), a tablet PC, a smart phone, a laptop computer, a desktop computer, a control system, a network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. It will be understood that a communication device of the subject disclosure includes broadly any electronic device that provides voice, video or data communication. Further, while a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methods discussed herein.

The computer system **1300** may include a processor (or controller) **1302** (e.g., a central processing unit (CPU), a graphics processing unit (GPU, or both), a main memory **1304** and a static memory **1306**, which communicate with each other via a bus **1308**. The computer system **1300** may further include a video display unit **1310** (e.g., a liquid crystal display (LCD), a flat panel, or a solid state display. The computer system **1300** may include an input device **1312** (e.g., a keyboard), a cursor control device **1314** (e.g., a mouse), a disk drive unit **1316**, a signal generation device **1318** (e.g., a speaker or remote control) and a network interface device **1320**.

The disk drive unit **1316** may include a tangible computer-readable storage medium **1322** on which is stored one or more sets of instructions (e.g., software **1324**) embodying any one or more of the methods or functions described herein, including those methods illustrated above. The instructions **1324** may also reside, completely or at least partially, within the main memory **1304**, the static memory **1306**, and/or within the processor **1302** during execution thereof by the computer system **1300**. The main memory **1304** and the processor **1302** also may constitute tangible computer-readable storage media.

Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

In accordance with various embodiments of the subject disclosure, the methods described herein are intended for operation as software programs running on a computer processor. Furthermore, software implementations can include, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein.

While the tangible computer-readable storage medium **622** is shown in an example embodiment to be a single medium, the term "tangible computer-readable storage medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "tangible computer-readable storage medium" shall also be taken to include any non-transitory medium that is capable of storing or encoding a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methods of the subject disclosure.

The term "tangible computer-readable storage medium" shall accordingly be taken to include, but not be limited to: solid-state memories such as a memory card or other package that houses one or more read-only (non-volatile) memories, random access memories, or other re-writable (volatile) memories, a magneto-optical or optical medium such as a disk or tape, or other tangible media which can be used to store information. Accordingly, the disclosure is considered to include any one or more of a tangible computer-readable storage medium, as listed herein and including art-recognized equivalents and successor media, in which the software implementations herein are stored.

Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Each of the standards for Internet and other packet switched network transmission (e.g., TCP/IP, UDP/IP, HTML, HTTP) represent examples of the state of the art. Such standards are from time-to-time superseded by faster or more efficient equivalents having essentially the same functions. Wireless standards for device detection (e.g., RFID), short-range communications (e.g., Bluetooth, WiFi, Zigbee), and long-range communications (e.g., WiMAX, GSM, CDMA, LTE) are contemplated for use by computer system **1300**.

The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

Although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, are contemplated by the subject disclosure.

The Abstract of the Disclosure is provided with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

What is claimed is:

1. A communication device, comprising:

an antenna comprising an antenna feed point having an associated load impedance of the antenna;

a tunable circuit coupled to the antenna feed point and having a variable reactive impedance adjustable to compensate for a change in the load impedance of the antenna;

a tuning sensor in communication with the tunable circuit and providing a sensor signal based on a mode of operation of the communication device;

a memory that stores executable instructions; and

a processor coupled to the memory, the tuning sensor, the tunable circuit, and the antenna, wherein the processor, responsive to executing the instructions, performs operations comprising:

presenting a first prompt at a user interface of the communication device to calibrate the communication device; and

detecting user input at the user interface responsive to the first prompt;

initiating a mode of operation of the communication device responsive to the detecting of the user input;

measuring the sensor signal to determine an adverse state comprising the change in the load impedance of the antenna caused by the mode of operation of the communication device;

determining a tuning state based on the sensor signal;

tuning the tunable circuit according to the tuning state to compensate for the adverse state;

storing the tuning state in a look-up table indexed according to the mode of operation of the communication device;

detecting a reinitiating of the mode of operation of the communication device; retrieving, in response to the detecting of the reinitiating of the mode and without performing a sensor signal measurement, the tuning state from the look-up table based on the mode of operation of the communication device; and

tuning the tunable circuit according to the tuning state retrieved from the look-up table.

2. The communication device of claim **1**, wherein the initiating of the mode of operation of the communication device comprises:

presenting a second prompt requesting an initiation of the mode of operation of the communication device;

detecting user input; and

initiating the mode of operation of the communication device responsive to detecting the user input, and

wherein the measuring the signal to determine the adverse state comprises using the tuning sensor.

3. The communication device of claim 1, wherein the adverse state comprises the change in the load impedance of the antenna, and

wherein the detecting of the reinitiating of the mode of operation of the communication device comprises detecting one of a physical configuration of the communication device, a function of the device, or both.

4. The communication device of claim 1, wherein the adverse state comprises a range of load impedances of the antenna, and wherein the determining of the tuning state comprises:

determining a reflection coefficient from the signal, wherein the reflection coefficient is indicative of the adverse state, corresponding to the range of load impedances of the antenna; and

determining the tuning state from the reflection coefficient to compensate for the range of load impedances of the antenna.

5. The communication device of claim 1, wherein the mode of operation of the communication device comprises a communication session.

6. The communication device of claim 5, wherein the communication session is one of a voice communication session or a data communication session.

7. The communication device of claim 5, wherein the communication session is one of a circuit-switched communication session or packet-switched communication session.

8. The communication device of claim 5, wherein the communication session conforms to a long term evolution communication protocol.

9. The communication device of claim 1, wherein the mode of operation of the communication device comprises an execution of a software application.

10. The communication device of claim 9, wherein the software application is a video game.

11. The communication device of claim 1, wherein the determining of the tuning state comprises:

determining a measure of a received signal strength indicator from the signal; and

determining the tuning state from the received signal strength indicator.

12. The communication device of claim 1, wherein the tunable circuit comprises a fixed reactive element controlled by a semiconductor device to produce a variable reactance.

13. The communication device of claim 1, wherein the tunable circuit comprises a fixed reactive element controlled by a micro-electro-mechanical systems device to produce a variable reactance.

14. The communication device of claim 1, wherein the tunable circuit comprises a variable reactive element controlled by a micro-electro-mechanical systems device to produce a variable reactance.

15. The communication device of claim 1, wherein the tunable circuit comprises a variable reactive element controlled by a bias signal that varies a dielectric constant of the variable reactive element to produce a variable reactance.

16. The communication device of claim 1, wherein the tunable circuit comprises one of a tunable matching network coupled to the antenna to compensate for the change in the load impedance of the antenna, a compensation circuit to compensate for mutual coupling between the antenna and another antenna of the communication device, an amplifier tuning circuit to control operations of an amplifier of the communication device, a filter tuning circuit to alter a pass band of a filter of the communication device, or combinations thereof.

17. The communication device of claim 1, wherein the signal is received from the antenna, and wherein the tuning of the tunable circuit according to the tuning state retrieved from the look-up table is performed without repeating the measuring of the signal to determine the adverse state.

18. The communication device of claim 1, wherein the communication device is one of a cellular telephone, a tablet, or a computer.

19. A tangible storage device, comprising executable instructions, which when executed by a processor, cause the processor to perform operations, comprising:

presenting a prompt at a user interface of a communication device to calibrate the communication device; and

detecting user input at the user interface responsive to the prompt;

identifying responsive to the detecting of the user input a mode of operation of the communication device in communication with an antenna;

measuring a signal to determine an adverse effect on a performance metric of the communication device, wherein the adverse effect comprises a change in a load impedance of the antenna, and wherein the signal comprises an indication of the change in load impedance of the antenna;

determining a tuning state based on the signal;

tuning a circuit having a variable reactance according to the tuning state to compensate for the change in the load impedance of the antenna;

storing in a memory the tuning state in association with the mode of operation of the communication device;

detecting a reoccurrence of the mode of operation of the communication device;

retrieving the tuning state from the memory based on the mode of operation of the communication device and without repeating of the measuring of the signal; and

tuning the circuit according to the tuning state retrieved from the memory.

20. The tangible storage device of claim 19, wherein the measuring the signal to determine the adverse effect comprises measuring the signal at any stage of a transceiver coupled to the antenna, and

wherein the signal comprises one of transmit power, transmitter efficiency, receiver sensitivity, power consumption, frequency band selectivity, linearity, efficiency of power amplifiers, or specific absorption rate requirements.

21. The tangible storage device of claim 19, wherein the circuit comprises one of a variable capacitor, a variable inductor, or combinations thereof, and wherein the measuring the signal to determine the adverse effect comprises using one of a directional coupler, a voltage divider, or a combination thereof.

22. The tangible storage device of claim 19, wherein the mode of operation of the communication device is one of a data communication session, a voice communication session, or execution of a software application.

23. A method, comprising:

presenting, by a communication device comprising a processor, a first prompt at a user interface of the communication device to calibrate the communication device; and

detecting, by the communication device, user input at the user interface responsive to the first prompt;

initiating, by the communication device, a mode of operation of the communication device in communication with a load impedance, wherein the initiating of the mode of operation is responsive to the detecting of the user input;

measuring, by the communication device, a signal to determine an adverse operational effect on the communication device, wherein the adverse effect comprises a change in the load impedance, and wherein the signal comprises an indication of the change in the load impedance;

determining, by the communication device, a tuning state based on the signal to compensate for the adverse operational effect;

tuning, by the communication device, a circuit of the communication device having a variable reactance according to the tuning state;

storing, by the communication device, the tuning state in a memory of the communication device, wherein the tuning state is retrievable from the memory based on the mode of operation of the communication device; and

tuning, by the communication device, the circuit according to the tuning state retrieved from the memory responsive to detecting a reoccurrence of the mode of operation of the communication device and without using a tuning sensor.

24. The method of claim **23**, wherein the initiating of the mode of operation of the communication device, comprises:

presenting, by the communication device, a second prompt at a user interface of the communication device to initiate a calibration process; and

initiating, by the communication device, the mode of operation of the communication device responsive to detecting user input at the user interface.

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